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A STATISTICAL STUDY OF THE LIKELY INFLUENCE OF SOME CAUSATIVE FACTORS ON THE TEMPERATURE CHANGES SINCE 1665

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SUMMARY

An estimated hemispheric temperature anomaly based on smoothed central England temperatures has been produced. The multiple regression equation of this series with values of volcanic dust veil index (DVI), Wolf number and carbon dioxide content has been worked out for the whole period 1665–1974 and for a selection of epochs within this span of 310 years.

The study provides little or no confirmation of the cooling effect of volcanic dust shown by the data for the most recent 100 years. The results for the relation between hemispheric temperature and Wolf number are similarly contradictory.

The study does nothing either to contradict or to weaken the indication of warming due to carbon dioxide demonstrated by the data for the most recent 100 years.

INTRODUCTION

In an earlier paper Miles and Gildersleeves (1977) reported on a statistical study of the temperature changes over the last hundred years. From the point of view of such a study this period has the drawback that several of the quantities examined have just one maximum and one minimum and therefore a single coincidence could lead to an apparent strong association. For example, the temperature itself has low values over the first 30 or so years, then higher values apart from the last decade. The carbon dioxide curve has nearly this pattern and the amount of volcanic dust has nearly the opposite shape. The amount of sunspot activity also steadily increased from low values in the first 50 years to higher values in the second 50 years.

Neither the total effect of these three factors on the hemispheric temperature nor the size of their relative contributions is known with such certainty that one can assert categorically that their apparent association over this century is not due to coincidence.

In the period back to 1665 there are two or three periods of low volcanic activity and about the same number with high activity comparable to the period 1870–1910 as can be seen from Figure 1. Likewise the sunspot numbers show three main periods of high values and two of low values as can be seen

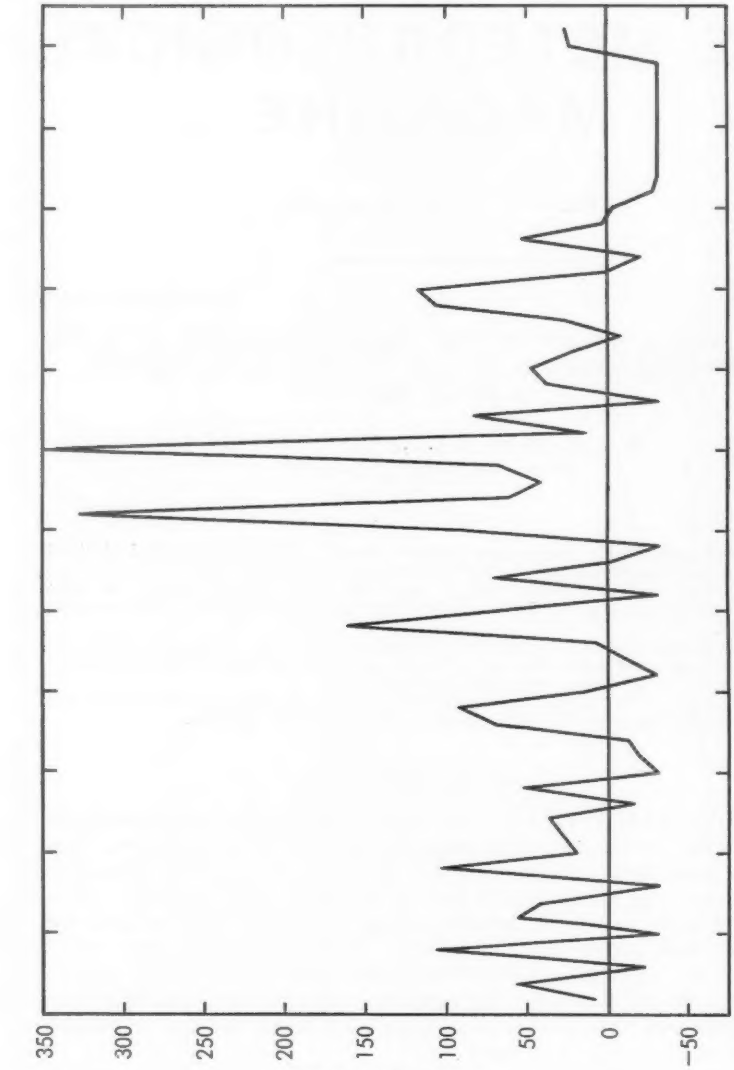

FIGURE 1—FIVE YEAR MEAN ANOMALIES OF DUST VEIL INDEX
Values are plotted against the first year of each five year period.

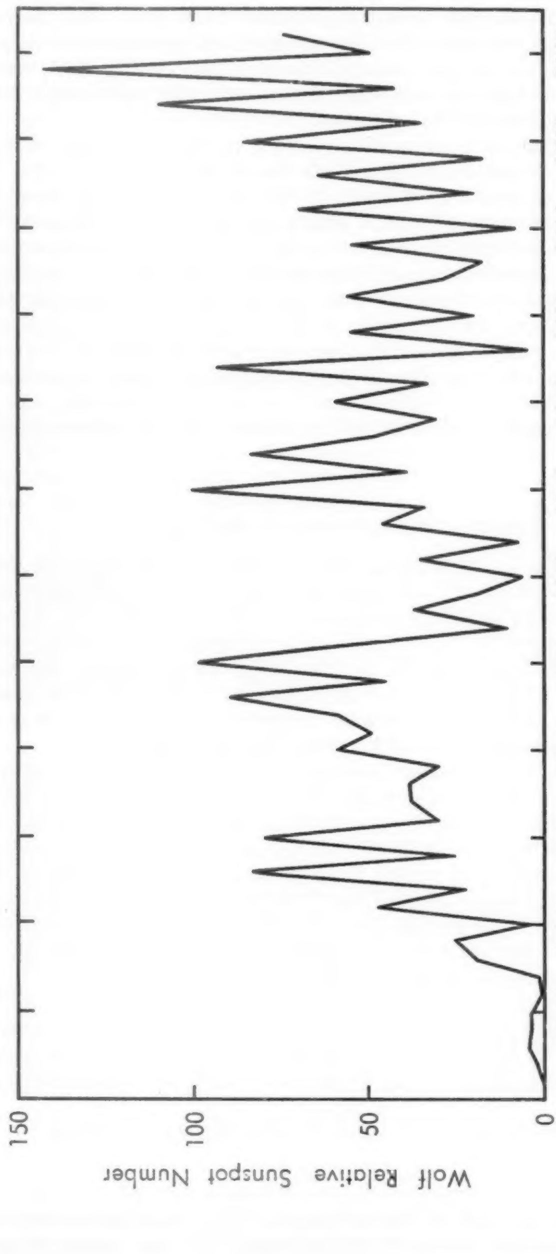

FIGURE 2—FIVE YEAR MEANS OF WOLF RELATIVE SUNSPOT NUMBERS
Values are plotted against the first year of each five year period.

from Figure 2. There is besides nearly 50 years of almost zero sunspot number—the now well-known Maunder Minimum which is dated 1650–1705. About the natural variations of the carbon dioxide content of the atmosphere in this time we know little, but it is thought unlikely (Bacastow and Keeling, 1972) that they were comparable with the increase which has accompanied increasing industrial activity in the late 19th and 20th centuries.

The three principal series of northern hemisphere temperatures—those due to Willett (1950), Mitchell (1961) and Budyko (1969)—all begin after 1870. There is a series compiled by Köppen (1914) and extended by Humphreys (1940) which goes back to 1750, and which has been used by Bray (1971) to study the effect of volcanic eruptions on temperature. The conclusion reached, namely that the temperature is lower than would be expected in the second year after major eruptions, has recently been quoted by Pollack and his fellow-workers (Pollack *et alii*, 1976; Baldwin *et alii*, 1976) in support of a theoretical model of radiative balance and stratospheric aerosol concentration. It is important therefore to consider how closely the Köppen series, based of necessity on a small number of observing stations mainly in temperate latitudes, represents the hemispheric temperature variations or whether it can be improved upon in any way.

Temperature series used in this study

For the short time when the Köppen series overlaps with the Mitchell–Budyko series (1870–1920) the correlation of the five year means is 0·16 compared with a value of 0·60 between the Mitchell–Budyko and Manley (1974) central England series for the same period. The relation of the Köppen series is greatly diminished by a very doubtful value for the year 1871, but nevertheless the relative value of the correlation indicates that the variations of the hemispheric temperature may be more closely represented by a single homogeneous series than by an assembly of stations some of which may be inhomogeneous.

With this in mind some further comparison of the hemispheric and central England temperatures was undertaken for the full period 1870–1969. The correlation of the five year means is 0·68 and the standard deviations are 0·20 K for the hemispheric temperature and 0·32 K for the central England temperature. Hence further smoothing of central England temperatures might be necessary to eliminate regional effects. Accordingly 10 year means of the central England temperature centred at the middle year of the five year means of the hemispheric series were formed, and these show a correlation coefficient over the 100 years of 0·81; their standard deviation is 0·25 K.

This suggests that a temperature regressed from the 10 year means of central England temperature might be a useful guide to the hemispheric temperature changes before 1870, but it must be remembered that these probably represent the temperature north of 30°N since the tropical oceans are scarcely represented at all.

A series has accordingly been formed from the regression relation

$$T_{\text{hemi}} = 0{\cdot}62\ T_{\text{CE}},$$

where T_{hemi} is the anomaly of the estimated 5 year mean hemispheric temperature and T_{CE} is the anomaly of the centred 10 year mean of central

England temperature, that is to say 10 years 1868–77 would be used to derive the hemispheric anomaly for the five years 1870–74. Both anomalies are with respect to the mean for the period 1870–1969, which for the central England series has been taken as 9·3 °C.

The values of this estimated series are shown in Figure 3, where the Köppen–Humphreys values are also plotted for comparison. The following comments may be appropriate.

(1) The main peaks and troughs in the two series occur nearly together; the 1870–74 minimum in the Köppen series is a notable exception, which, as was mentioned earlier, is largely due to a doubtful value for 1871.

(2) The standard deviation of the 5 year means of the estimated series is 0·17 K compared with 0·28 K for the Köppen series; the estimated series is nearer the standard deviation of 0·20 K shown by the Mitchell–Budyko series for 1870–1969.

Data used in the study

The five year means of temperature anomaly, dust veil index, Wolf number and carbon dioxide content used in the study are given in Table I.

The temperature anomalies are the estimated values described in the previous section. The dust veil index means are taken from Lamb (1970) with amendments as given by Lamb (1977) included. The Wolf number means are from Waldmeier (1961) for 1750 onwards and from Eddy (1976) before 1750. The carbon dioxide values are as used by Miles and Gildersleeves (1977) after 1870 and have been taken as constant at the 1870–74 value for the time back to 1665.

No attempt has been made to introduce an index of the ice because the earlier study showed that its effect is mainly a feedback one which enhances the temperature changes produced by other factors.

Method of procedure and results

The multiple regression scheme described by Miles and Gildersleeves (1977) for the previous study was used again. Six separate runs of this program covering different time periods were made and these are listed in Table II together with the correlation coefficients obtained.

The first two runs go back to the earliest date, 1665, differing only in the end time. Both show the Wolf number as having the strongest relation with temperature. This arises largely because the lowest temperatures occur at the time of the Maunder Minimum. The period of the Maunder Minimum is removed in runs 3 and 4 to see what the relation is like outside this remarkable period. As runs 4 and 5 show, it is a lot weaker and arises entirely from the last 100 years. The 155 years from 1715 to 1869 show no correlation between the variables at all.

These five runs also indicate that the negative correlation of temperature with volcanic dust arises almost entirely from the last 100 years. It might be argued that five year means are an inappropriate way of revealing this relationship since the dust from even strong eruptions may have largely fallen out within two to three years, but Lamb (1970) found high correlations with decadal means. There may also be a lag of several years in the atmospheric response to volcanic dust. The various studies do not agree sufficiently well on these points to make it worth while to enter the dust veil with a few years' lead in this study. Perhaps

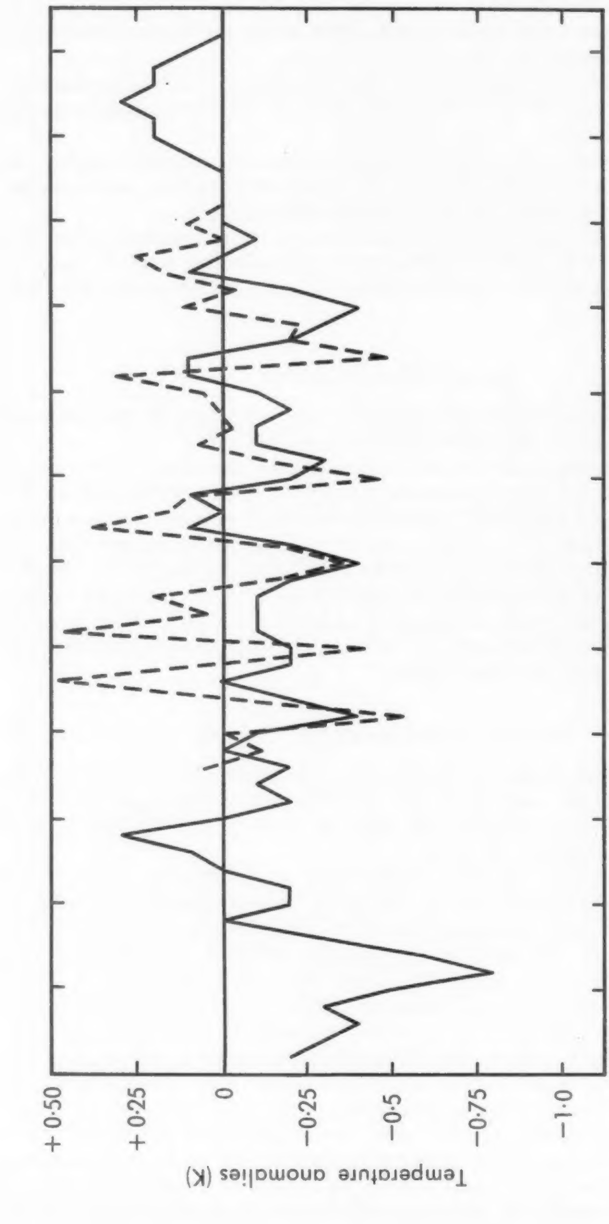

FIGURE 3—FIVE YEAR MEANS OF NORTHERN HEMISPHERE TEMPERATURE ANOMALIES

—— estimated from central England temperature
– – – derived from the Köppen–Humphreys temperature series
Values are plotted against the first year of each five year period.

TABLE I—FIVE YEAR MEANS OF TEMPERATURE ANOMALY, DUST VEIL INDEX, WOLF NUMBER AND CARBON DIOXIDE CONTENT

	Temp. anomaly K	DVI	Wolf No.	CO_2		Temp. anomaly K	DVI	Wolf No.	CO_2
1665–69	—0·2	7	0	—14					
1670–74	—0·3	58	2	—14	1820–24	0·1	61	7	—14
1675–79	—0·4	—22	4	—14	1825–29	0·0	36	46	—14
1680–84	—0·3	108	3	—14	1830–34	0·1	68	34	—14
1685–89	—0·5	—32	3	—14	1835–39	—0·2	343	101	—14
1690–94	—0·8	53	0	—14	1840–44	—0·3	13	30	—14
1695–99	—0·6	39	1	—14	1845–49	—0·1	81	84	—14
1700–04	—0·3	—32	18	—14	1850–54	—0·1	—32	49	—14
1705–09	0·0	103	25	—14	1855–59	—0·2	38	36	—14
1710–14	—0·2	19	3	—14	1860–64	—0·1	48	65	—14
1715–19	—0·2	26	47	—14	1865–69	0·1	24	33	—14
1720–24	0·0	30	22	—14	1870–74	0·1	—8	93	—14
1725–29	0·1	—17	83	—14	1875–79	—0·2	28	10	—13
1730–34	0·3	54	23	—14	1880–84	—0·3	108	55	—12
1735–39	0·0	—32	79	—14	1885–89	—0·4	118	21	—11
1740–44	—0·2	—20	31	—14	1890–94	—0·2	2	56	—10
1745–49	—0·1	—14	43	—14	1895–99	0·1	—20	34	—9
1750–54	—0·2	70	44	—14	1900–04	0·0	53	17	—8
1755–59	0·0	92	31	—14	1905–09	—0·1	4	55	—7
1760–64	—0·1	17	58	—14	1910–14	0·0	—2	8	—6
1765–69	—0·4	—32	49	—14	1915–19	0·0	—29	70	—4
1770–74	—0·2	—10	63	—14	1920–24	0·0	—32	20	—3
1775–79	0·0	7	80	—14	1925–29	0·0	—32	64	—1
1780–84	—0·2	162	45	—14	1930–34	0·1	—32	17	1
1785–89	—0·2	58	98	—14	1935–39	0·2	—32	86	3
1790–94	—0·1	—32	61	—14	1940–44	0·2	—32	35	6
1795–99	—0·1	72	11	—14	1945–49	0·3	—32	110	8
1800–04	—0·1	4	37	—14	1950–54	0·2	—32	42	11
1805–09	—0·2	—32	18	—14	1955–59	0·2	—32	143	14
1810–14	—0·4	88	7	—14	1960–64	0·1	24	49	17
1815–19	—0·2	325	35	—14	1965–69	0·0	26	74	21

Temperature anomalies are the estimated values described in the foregoing text. Dust veil index (DVI) means are taken from Lamb (1970) as amended by Lamb (1977). The Wolf number means are from Waldmeier (1961) for 1750 onwards and from Eddy (1976) for the years before 1750. The carbon dioxide values are as used by Miles and Gildersleeves (1977) after 1870 and have been taken as constant at the 1870–74 level from 1869 back to 1665.

TABLE II—CORRELATION COEFFICIENTS BETWEEN THE TIME SERIES USED

	Temperature	DVI	Wolf No.
Run 1 (1665–1969)			
DVI	—0·23		
Wolf No.	+0·44	—0·05	
CO_2	+0·49	—0·30	+0·35
Run 2 (1665–1869)			
DVI	+0·01		
Wolf No.	+0·37	+0·14	
CO_2	(not entered—constant value throughout)		
Run 3 (1715–1969)			
DVI	—0·36		
Wolf No.	+0·23	—0·06	
CO_2	+0·52	—0·32	+0·29
Run 4 (1715–1869)			
DVI	—0·12		
Wolf No.	—0·03	+0·10	
Run 5 (1870–1969)			
DVI	—0·80		
Wolf No.	+0·44	—0·33	
CO_2	+0·61	—0·44	+0·41
Run 6 (1750–1919)			
DVI	—0·24 (—0·26)		
Wolf No.	+0·05 (—0·26)	+0·09	
CO_2	+0·20 (+0·14)	—0·23	—0·11

Bracketed values in Run 6 refer to the Köppen–Humphreys temperature series.

the most interesting feature of these five runs is the consistently high correlation between CO_2 and temperature whenever CO_2 was included.

Run 6 covers the period of the Köppen–Humphreys series and the figures in brackets are for their temperature series. The correlation with volcanic dust is low with both series, which suggests that Bray's (1971) conclusion should be accepted with caution. The values of the temperature change are exaggerated by the larger standard deviation of this series. The Wolf number correlation is negligible for the estimated temperature series and has a negative value with a low statistical significance for the Köppen–Humphreys series, whereas in all other runs it has shown a positive correlation with temperature.

FURTHER DISCUSSION OF RESULTS

Table III shows the coefficients of the various terms in the multiple regression equations for the six runs. The multiple correlation coefficients given in the last column suggest that the variance in the temperature curve can be best explained for the past 100 years and least well explained for the middle period 1715–1869. In part this may be due to the temperature series being a better approximation to the true hemispheric temperature variations for the last 100 years than in the previous 150 years. The improved correlation when the earliest 50 years are brought in (run 2 compared with run 4) thus remains puzzling and leaves one wondering whether there is any physical association between the very low temperatures during this time and the very low sunspot activity.

TABLE III—COEFFICIENTS OF VARIOUS TIME SERIES IN THE MULTIPLE REGRESSION EQUATIONS (THOSE MARKED WITH AN ASTERISK ARE NON-SIGNIFICANT)

Run No.	DVI	Wolf No.	CO_2	Intercept	*N*	*R*
1 (1665–1969)	—0·0003	0·0021	0·0086	—0·1023	61	0·58
2 (1665–1869)	—0·0001*	0·0026	—	—0·2629	41	0·37
3 (1715–1969)	—0·0005	0·0006	0·0079	—0·0007	51	0·56
4 (1715–1869)	—0·0002*	—0·0002*	0*	—0·1032	31	0
5 (1870–1969)	—0·0025	0·0006	0·0049	—0·0088	20	0·86
6 (1750–1919)	—0·0003	0·0005	0·0080	—0·0018	34	0·28
	(—0·0007)	(—0·0023)	(0·0058)	(+0·1376)	34	0·35

N is the number of observations and *R* the multiple regression coefficient. Bracketed values in Run 6 refer to the Köppen–Humphreys temperature series.

TABLE IV—TEMPERATURE CHANGES ASSOCIATED WITH GIVEN CHANGES (Δ) IN THE VARIOUS FACTORS IN THE MULTIPLE REGRESSION EQUATION

Run	Δ	DVI Effect on temperature *kelvins*	Δ	Wolf No. Effect on temperature *kelvins*	Δ	CO_2 (ppm) Effect on temperature *kelvins*
1	375	—0·11	143	+0·30	35	+0·30
2	—	—	101	+0·26	—	—
3	375	—0·19	136	+0·08	35	+0·28
4	—	—	—	—	—	—
5	150	—0·38	135	+0·08	35	+0·18
6	375	—0·13	94	—	10	+0·08
		(—0·26)		(—0·22)		(+0·06)

Bracketed values in Run 6 refer to the Köppen–Humphreys temperature series.

Table IV contains the estimates of the contribution to temperature change attributed to the various factors in the analysis.

The contribution of volcanic dust for a change of −150 units (that is to say the change from the 1880s to the 1930s) varies from +0·05 K to +0·38 K (using only the significant values). The larger value derives from the last 100 years while the lower value comes from the whole period. The studies by Pollack *et alii* (loc. cit.) and their application by Miles and Gildersleeves (1978) suggest that to depress the five year mean temperature by from 0·2 to 0·3 K, two successive five year periods with a high DVI, such as 1880–84 and 1885–89 are required. In the period 1715–1869 four such periods can be recognized. They are listed in Table V with the observed temperature anomaly and the depression below the prevailing 50 year average.

TABLE V—TEMPERATURE ANOMALIES FOR DECADES WITH MAINTAINED HIGH DVI

	Mean temperature anomaly *kelvins*	Depression below 50 year mean *kelvins*
1750–59	—0·10	—0·01
1780–89	—0·20	—0·04
1810–19	—0·30	—0·19
1830–39	—0·05	+0·08

The period 1735–49 with very low DVI had a mean temperature slightly below the prevailing mean. Another period 1765–79 with very low DVI was also

below the prevailing mean. The effect of volcanic dust appears therefore to be small, say less than 0·1 to 0·2 K for major series of eruptions, or variable as between different eruptions, which is a possibility raised by recent studies by Pollack *et alii* (loc. cit.).

The sunspot contribution for the change in the mean value of the Wolf number of about 50 from the early 20th century to the epoch 1935–60 varies from −0·1 to +0·1 K. The effect of a Wolf number of nearly zero during the Maunder Minimum cannot therefore be much more than 0·1 K above or below the general level. This does not of course apply if the complete absence of spots means a totally different radiation regime as Eddy (1976) has claimed.

The total carbon dioxide contribution from runs going up to 1969 varies from +0·18 K to +0·30 K. This range, assuming a linear increase of the effect with CO_2 concentration, corresponds to a warming of between 1·6 and 2·6 K for a doubling of the concentration from its mean value of 305 parts per million (ppm) or between 1·3 and 2·1 K if the effect is proportional to the square root of the CO_2 concentration. This is rather less than the value of 2·9 K computed by Manabe and Wetherald (1976) but the results from a regression equation would tend to lie below the true value. Between 1740 and 1869, and 1870 and 1969, there is a marked change in the linear trend of temperature, changing from 0·1 K/100 years in the earlier period to 0·4 K/100 years in the later one. This change is mirrored very closely by the change in CO_2 (Table I) and this visual impression is confirmed by inspection of the correlation coefficients (Table II) particularly for runs 1 and 3.

Figure 4 shows the curve of predicted temperature anomalies using the regression equation obtained from run 1 and it can be seen that this broad pattern of temperature change is well fitted by the equation. Noting that the change between 1870 and 1969 in CO_2 concentration is 35 ppm and that the average change in Wolf number over the same period is approximately 50 and using the coefficients for run 1 in Table III, 75 per cent of the rise in temperature is attributed to changes in CO_2 and 25 per cent to changes in the Wolf number.

CONCLUSIONS

The extension of the period examined back to 1715 provides little or no confirmation of a cooling effect due to volcanic eruptions indicated by the period 1870–1969. The data do not appear to be good enough to enable a firm conclusion, or one that applies to all volcanic episodes, to be reached.

This period 1715–1969 also provides somewhat contradictory indications about the relation between Wolf number and temperature. They appear not to be related for the period 1715–1869 and the small positive contribution after 1870 (see Table IV, run 5) can be as well explained by the effects of volcanic dust or CO_2 or both. From the Köppen–Humphreys data for 1750–1919 there is a negative relation of low statistical significance.

The addition of the period 1665–1715 appears to give some confirmation to the positive relation between Wolf number and temperature shown in the modern period, but even so would imply a depression of no more than 0·1–0·2 K during the time of zero sunspots unless there was at that time a totally different relation between radiation and sunspot number than otherwise prevails. The carbon dioxide effect is the one which emerges most consistently, and provides the best explanation of the enhanced linear trend after 1870.

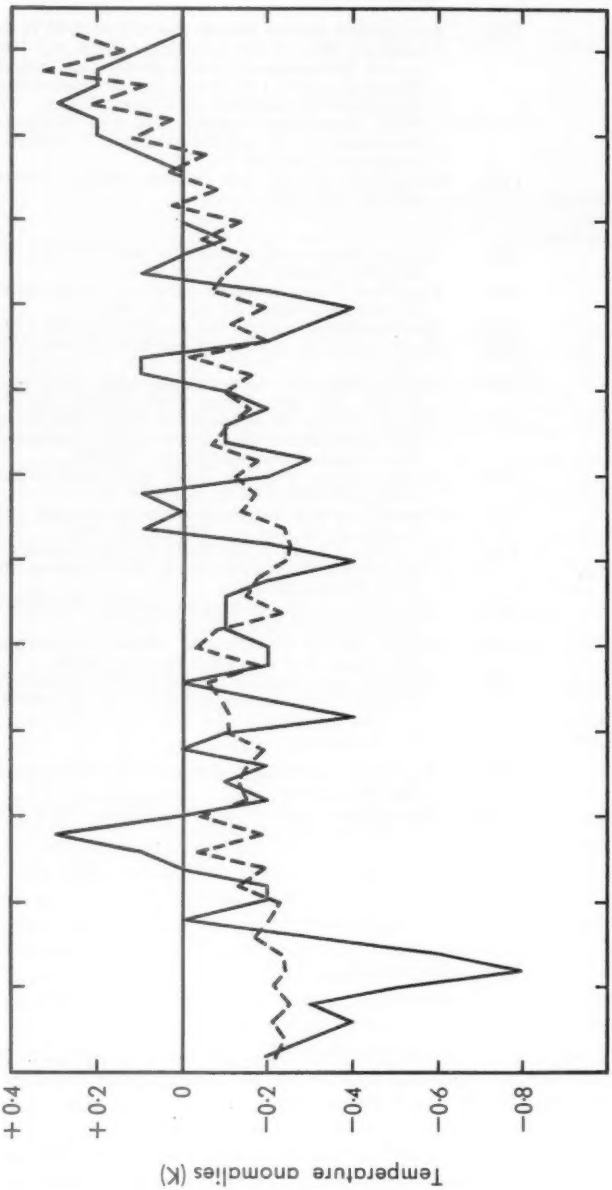

FIGURE 4—ESTIMATED AND PREDICTED FIVE YEAR MEAN TEMPERATURE ANOMALIES 1665–1969

—— estimated from regression
– – – predicted from run 1
Values are plotted against the first year of each five year period.

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A GUIDE TO SATELLITE PICTURE ANALYSIS

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SUMMARY

The satellite picture taken by NOAA 5 in orbit 851 on 6 October 1976 showed many synoptic features. An attempt is made to explain how to identify these features and to incorporate them into the analysis of charts in common use in the Meteorological Office.

Many meteorological offices are receiving satellite pictures directly from Bracknell which the forecasting staff at these offices analyse locally. Other meteorological offices are only receiving nephanalyses, which are freehand analyses of cloud structure and other features of synoptic importance, produced by an analyst at the Central Forecasting Office (CFO) at Bracknell. On 6 October 1976, pictures from NOAA 5, orbit 851, showed many features which are of interest to both surface and upper-air analysts. Reproduced on the following pages are the visual satellite photograph (Plate I), the nephananalysis (Figure 1), the surface plus thickness chart, and the 500 mb chart for 12 GMT on 6 October 1976 (Figures 2 and 3). The various areas of interest that will be discussed are annotated on the nephanalysis for easy reference.

The cold front 'V' may be positioned on the surface chart by inspection. Active cold fronts (ana-fronts) are positioned to the rear edge of the cloud band, whereas weak, slow-moving cold fronts (kata-fronts) are positioned to the forward edge. Cold fronts also indicate a zone of strong baroclinicity, and thickness lines are commonly closely packed on the poleward side of the cold front cloud band. Jet streams are often associated with cold fronts and are located to the poleward side of the cloud bands. They can often be accurately positioned by an abrupt boundary on the poleward side of the cirrus cloud: see position 'W'. Because of the elevation of the sun this cirrus edge frequently casts a shadow on the lower cloud to the poleward side: see positions 'V' and 'W'.

On infra-red satellite pictures jet-stream cirrus can often be seen as a bright, white, and long, narrow band. Trailing cold fronts often have wave development, and areas of potential wave development are frequently associated with 'comma clouds': see positions 'X'. These comma clouds are usually observed in areas of maximum positive vorticity advection (PVA), and are the result of moving vorticity centres to the rear of a polar front. Because of the ascent of air in the PVA areas there is usually an area of subsidence ahead of the comma cloud seen as a clear area. When the comma cloud moves to within about 350 n. mile of a frontal band, wave development can be expected. As a cloud pattern associated with vorticity approaches a front, the frontal cloud band broadens and becomes more concave-shaped (to the cold side), and cirrus cloud can often be seen streaming ahead of the wave. The surface position of the wave is under the bulge close to where the curvature of the rear edge of the frontal cloud band changes from concave to convex (at position 'Y'). Over the developing wave the thickness lines curve anticylonically, with the thermal jet located just northwards

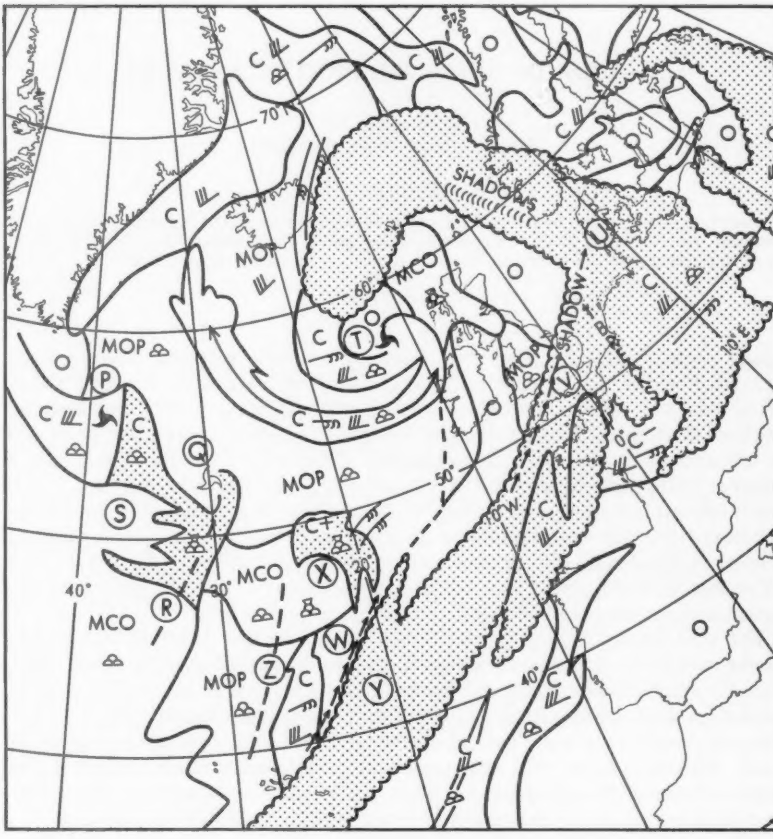

FIGURE 1—NEPHANALYSIS FOR 12 GMT ON 6 OCTOBER 1976

of the wave tip. Areas of maximum vorticity often occur just ahead of the 500 mb trough, and in satellite pictures the maximum vorticity is denoted by the comma cloud (PVA maximum). The 500 mb trough is therefore placed just behind the comma cloud as shown by 'Z'.

The area 'U' on the nephanalysis shows a cloud band running northwards and towards the vorticity centre and marks the position of the occlusion, while to the south is a warm sector. The cloud over the occlusion is lower and more lumpy than that over the warm sector, which is cirriform. This cloud change, which is sometimes enhanced on the satellite pictures by a shadow cast from the high cloud over the warm sector on to the lower cloud over the occlusion, denotes the continuation of the jet stream from the rear of the cold front. The point of occlusion should be placed just to the equatorial side of the demarcation line between the types of cloud, but the warm front cannot be located from

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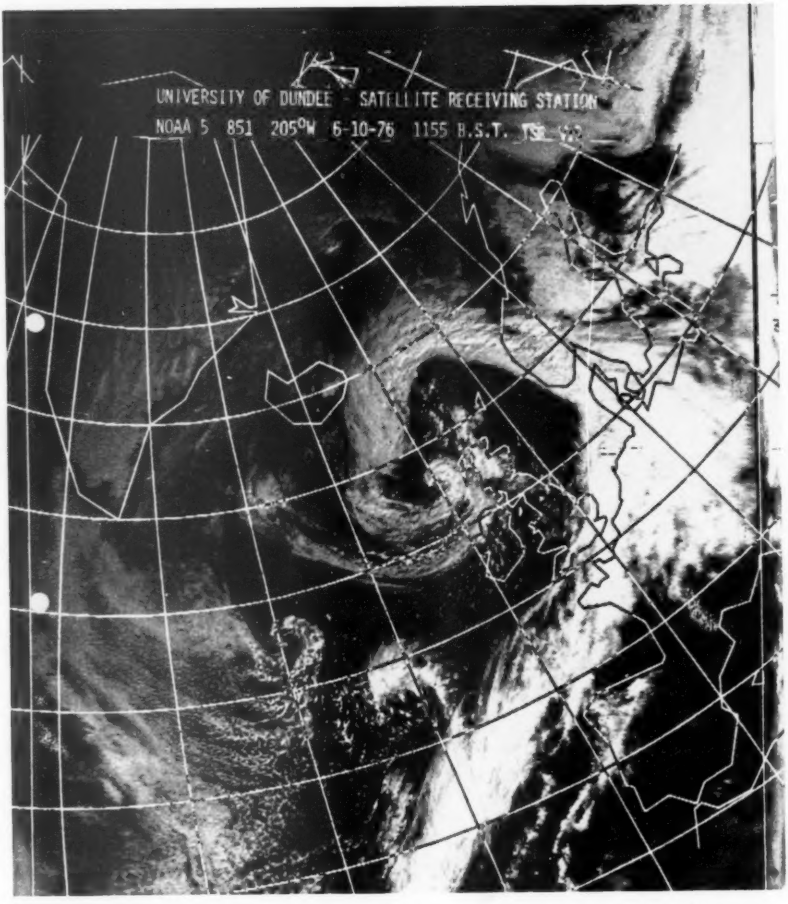

Photograph by the Department of Electronics and Electrical Engineering, Dundee University

PLATE I—PICTURE IN VISIBLE LIGHT FROM NOAA 5 AT 1055 GMT ON 6 OCTOBER 1976

To face page 207

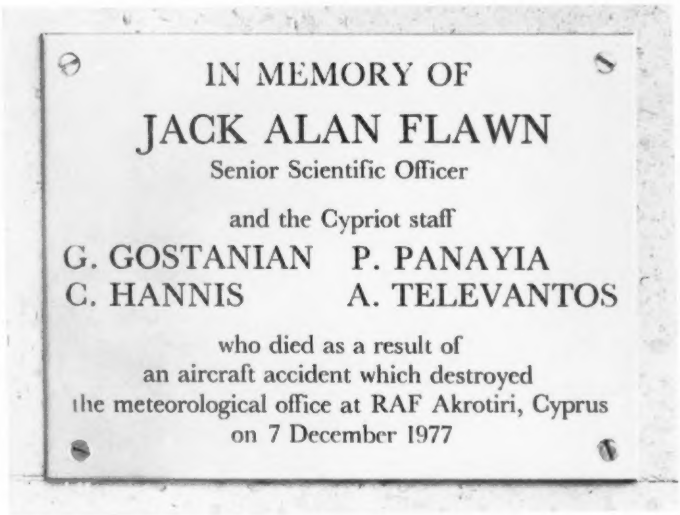

PLATE II—MEMORIAL PLAQUE IN THE ENTRANCE HALL OF THE METEOROLOGICAL OFFICE MAIN HEADQUARTERS BUILDING IN BRACKNELL

(See page 223.)

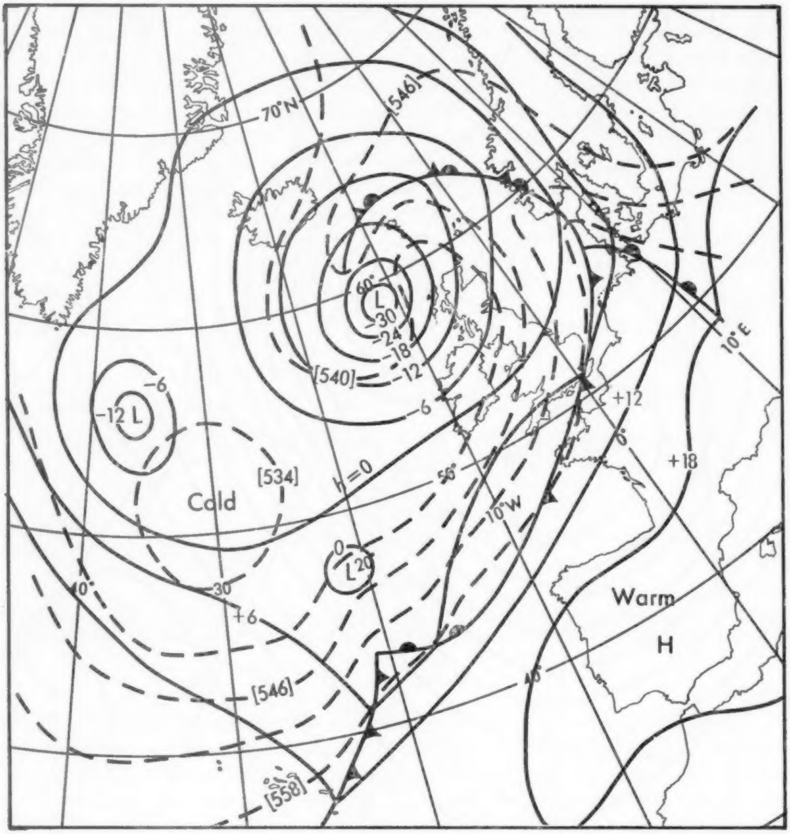

FIGURE 2—1000 mb HEIGHT AND 1000–500 mb THICKNESS CHART FOR 12 GMT ON 6 OCTOBER 1976

satellite pictures owing to the extensive cirrus shield ahead of it. Along the occlusion there is pronounced thermal ridging which has penetrated almost to the vortex centre. Warm sectors are usually homogeneous and there are very few thickness lines over them. To the rear of the occlusion there is a large clear area, which is caused by subsidence, and usually the more active and quickly moving the occlusion the larger the clear area.

The area marked 'T' on the nephanalysis shows a vorticity centre entering the dissipating stage. There are four stages in vorticity development that are discernible from satellite pictures. There is the comma cloud stage as seen in area 'X', and then, as the wave on a cold front develops, the curvature of the cloud bulge becomes more pronounced. The rear edge of the high cloud becomes more concave, and an area of lower thinner cloud appears along the rear edge of the wave. Rapid intensification of the circulation begins at about this time. In the

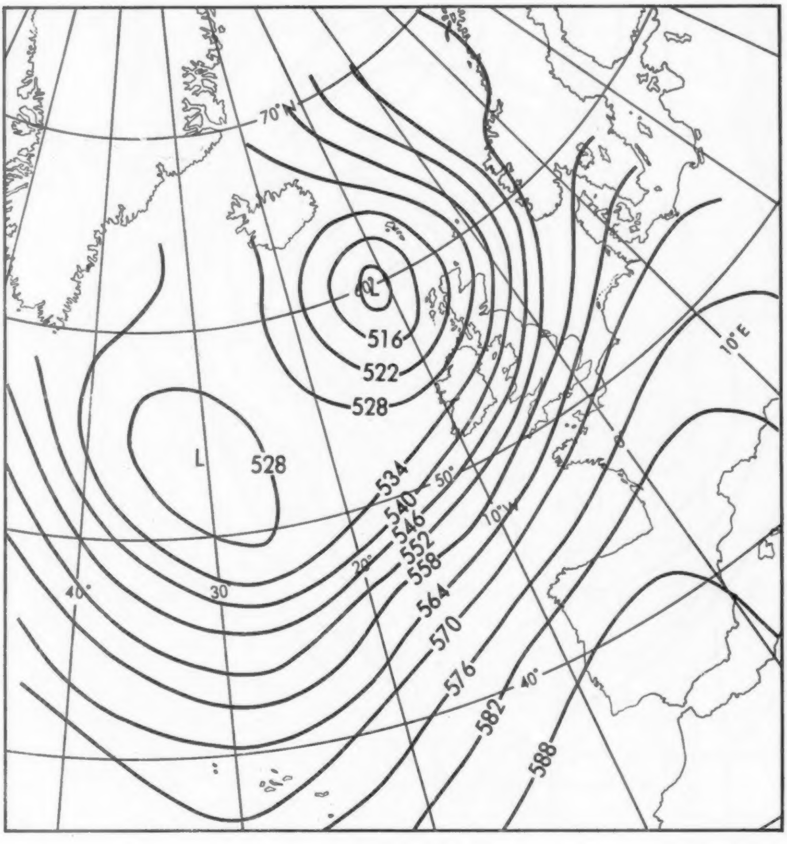

FIGURE 3—500 mb CHART FOR 12 GMT ON 6 OCTOBER 1976
Isopleths are labelled in geopotential decametres.

occluding stage the cloud begins to take on a spiral pattern and a clear or dry slot begins to form behind the front. In the mature stage the development has reached its maximum and the clear slot extends into the centre of the vortex. At this stage the vortex centre and the centres at the surface and in the mid troposphere are nearly coincident owing to the minimum tilt of the pressure centres with height. The dissipating stage is indicated where the vortex bands become fragmented and are mainly of medium- or low-level cumuliform and stratiform clouds. The frontal cloud band also becomes separated from the vortex centre. This pattern is usually associated with a 500 mb centre and a dissipating surface low.

In area 'S' on the nephanalysis polar air is moving southwards towards warmer seas. Cumulus humilis clouds will initially form in narrow lines at low levels, and these lines will closely approximate to the surface wind direction. When

these clouds develop into 'open cells' they become arranged parallel to the vertical wind shear though the cloud layer and are thus closely aligned with the thermal wind. Open cells denote deep convection and are associated with cyclonic flow, whereas 'closed cells' occur more often in anticyclonic flow. The curvature of the open cells indicates a thermal trough along 'R' centred on a thermal low as shown by the well-defined thermal vortex at 'Q'.

The vortex seen at 'P' is mainly of low-level cloud and suggests a surface low at this position. Also a surface low at 'P' together with a thermal low at 'Q' suggests that there must be a 500 mb low close to 'Q'.

This particular case shows how the satellite picture and the nephanalysis derived from it can aid the forecaster in analysing both the surface and upper-air charts. More detailed reading can be found in *WMO Technical Note* No. 124 and *ESSA Technical Report* NESC 51.

551.5:551.501.9:92

CO-OPERATING OBSERVERS AND THE CLIMATOLOGICAL NETWORK

By R. J. OGDEN
(Meteorological Office, Bracknell)

Summary

The origins and development of the United Kingdom Climatological Network are briefly described and the very large contribution made by non-professional observers is emphasized.

Introduction

The UK Climatological Network is in many ways a remarkable institution. In an age when our observational armoury includes satellites, radar and sophisticated automatic sampling and recording devices, the basic measurements at Network stations are still made with quite simple instruments; and despite the widespread modern trends for increased specialism and for services to be provided by the State, almost 90 per cent of Network stations are maintained by non-professional observers. These facts appear to suggest that the organization has simply failed to move with the times, but paradoxically the simple approach and the non-professional co-operation thereby acceptable, are the very reasons why the Network is so effective.

The purpose of a climatological observing network is to provide information from which the climatology of the country may be determined. It is essential for the observations to be made regularly to a common high standard, and for the spacing of the observing stations to be close enough to represent adequately the variations of climate to be found over different types of terrain in all parts of the country. But the basic observations of temperature, rainfall, sunshine, pressure, wind, humidity, visibility, weather and so on can be made by eye with the aid of simple instruments; if human observers are available in the right places, there is no need for complicated and expensive equipment. The UK Climatological Network has therefore been organized in a particularly cost-effective way by tapping the large reservoir of amateur interest in the weather and channelling the flow of information through professional filters. Without

the voluntary stations, it would be impossible to achieve the required network density; without the professional co-ordination, the necessary uniform standards would not be attained. The two components are complementary to each other and in combination they make the Network an alloy of great strength.

Origins of the Network

With the invention of instruments such as the thermometer, barometer and rain-gauge, it became possible during the 17th century to make simple meteorological measurements, and the scientific curiosity of an age in which the Royal Society was founded led a number of gentlemen to make regular observations and to compare notes. From these initially haphazard exchanges, by the early half of the 19th century a strong tradition of amateur interest in weather observing had developed and regular observing routines had been established at certain scientific institutions. The value of this work gradually came to be accepted by a wider public, and by the late 1870s, a few municipalities had set up their own local weather observing stations, as had several schools and colleges.

Before this, however, the electric telegraph had been invented in 1844, and this offered a means of collecting weather data within a few hours. The first daily weather report was published in a newspaper only four years later, primarily for the benefit of farmers. At that time, most of the telegraph lines were associated with the railways, and in 1849 the railway companies were persuaded to contribute regular weather observations for publication; James Glaisher travelled the country to organize a synoptic weather reporting network and to train railway staff as observers. When the Meteorological Department of the Board of Trade was formed in 1855 under Admiral FitzRoy (becoming the Meteorological Office in 1863), the safety of life at sea was the major concern; with the co-operation of the coastguard service, further telegraphic observing stations were organized as an integral part of a new storm warning service for inshore shipping.

It may be said that the UK Climatological Network formally came into existence in 1884 when the *Monthly Weather Report* was first published, and from the outset we may distinguish the three strands that were brought together. Firstly there were the Co-operating Observers, both private and those at institutions or municipalities, whose contribution was voluntary; these people shared a common interest in the weather, and in many cases this interest amounted to a spirit of dedication that has enriched the network throughout its history. The second strand was formed by some of the Auxiliary Observers who had been recruited for the synoptic network; most of these observers were employed in jobs that were in some way weather-related, and their observations were made whilst on duty. At least one railway observing station (Hawes Junction) contributed to the 1884 Report, as did a number of coastguard stations. Finally there was the Meteorological Office itself which played the key organizational role that brought the Network into existence and which laid down, and by inspection maintained, the necessary uniform standards for observing.

Development of the Network

The growth of the Network from its inception to the present day is shown in Table I. It is remarkable that roughly a quarter of the stations that contributed to the first *Monthly Weather Report* in 1884 are still submitting returns 94 years later.

These 17 stations are:

Aberdeen	Hastings	Rothamsted
Armagh	Liverpool (Bidston)	Scarborough
Cambridge	Marlborough	Scilly (St Mary's)
Douglas	Nairn	Stonyhurst
Durham	Oxford	York
Falmouth	Plymouth	

A further 13 stations which are still reporting joined the Network before the turn of the Century:

Braemar	Glenlee	Sheffield
Cockle Park	Lowestoft	Southport
Colwyn Bay	Marchmont	Torquay
Eastbourne	Margate	
Fort Augustus	Rhyl	

TABLE I—THE UK CLIMATOLOGICAL NETWORK

Year	Met. Office stations	Auxiliary synoptic stations	Co-operative climatological stations	Total
1884	1	29	36	66
1890	1	30	46	77
1895	1	30	47	78
1900	1	25	48	74
1905	1	26	179	206
1910	3	30	209	242
1914	4	31	304	339
1920	20	26	274	320
1925	20	27	289	336
1930	22	27	298	347
1935	25	24	316	365
1938	25	25	313	363
1946	84	20	324	428
1950	77	23	347	447
1955	80	24	393	497
1959	73	25	453	551
1965	71	48	473	592
1970	73	57	526	656
1975	72	59	511	642
1977	69	56	499	624

Notes

1. Met. Office stations include outstations and observatories.
2. Co-operating stations include Health Resort and Agro-meteorological stations.
3. Stations in Southern Ireland were included in the Network until the Second World War, i.e. in the above Table for all years to 1938.
4. Figures refer to 31 December in each year.

As may be seen from the above lists, a number of municipal authorities had joined the Network before 1900. Sensing an increasing awareness of the advertising value of references in the national press to weather at the resorts, the Meteorological Office decided in 1912 to introduce the Health Resort scheme. Local authorities were encouraged to set up climatological stations which would be inspected annually to ensure that common high standards of observing were maintained; in exchange for submission of the normal climatological returns, the Office undertook to accept evening telegrams from the resorts and from these to prepare a daily bulletin of approved readings for the Press. Except that

since 1976 the evening reports have been collected by telephone, the scheme still operates as set up in 1912 and the climatological returns make a useful contribution to the data received from the Network.

Agricultural interest in climatology had also been apparent from the early days (for example Rothamsted), but it was not until 1924 that the Office took steps to organize this for the benefit of the Network. The interest in observing at agricultural colleges and research institutions arose from the need to monitor environmental conditions in connection with experimental work in crop management and animal husbandry; there were clear advantages for them in achieving uniform standards throughout the country, and these could most readily be obtained through the regular Meteorological Office inspections which were offered in exchange for routine climatological returns. A new class of Crop Weather (now called Agro-meteorological) stations was therefore introduced, and these have become a significant part of the Network. Although not included in this category, an important group of stations with somewhat similar interests has also been established by the Forestry Commission, Nature Conservancy and Field Studies Council.

For the first 35 years, the synoptic stations that were also part of the Climatological Network were almost entirely Auxiliary, the Meteorological Office contributing data only from a few Observatories. However, the applications of meteorology to artillery and flying became evident during the First World War, and from 1920, climatological returns were received from the meteorological offices (then called distributive stations) that had been established at Army units and airfields. Many new meteorological offices were needed to support the Royal Air Force during the Second World War and these too made returns. Fortunately the sharp post-war decrease in the number of offices associated with the Royal Air Force has been partly offset by the increase in those serving civil aviation and the general public, and the Office now makes a very substantial contribution to the total amount of data collected from the Network. Whereas the basic information supplied by all Network stations consists of readings made daily at 09 GMT, these alone give little indication of the important diurnal variations of weather; to obtain knowledge of that, hourly or at least 3-hourly observations are needed, and with the exception of a handful of Auxiliary stations, only the continuously manned meteorological offices can supply these.

Table II summarizes the present distribution of stations in the Network; in addition to the groups specifically mentioned above, certain stations run by Government, Water and other Public Authorities have now been enrolled.

The co-operating observers

Meteorological offices are manned by professional staff whose job it is to make weather observations, and the observers at Auxiliary stations are for the most part on duty for other purposes and also receive honoraria for their climatological work. By contrast, the co-operating observers as a class are sustained largely by their own interest in a task to which they have voluntarily put their hands. Admittedly, observers at stations which are sponsored by an Authority or Institution fit their meteorological work in with their other duties, and in some cases receive modest extra payments; but many of them carry out work far beyond that strictly paid for by their employers. Private observers, moreover, work entirely in their own time and in most cases purchase their own instruments;

TABLE II—CURRENT SPONSORSHIP OF STATIONS IN THE UK CLIMATOLOGICAL NETWORK

Sponsor		Percentage of Network stations
Meteorological Office		11
Auxiliary Station Authorities		9
Co-operating Station Authorities		80
Local Authorities (General)	12 } 19	
Local Authorities (Health Resorts)	7 }	
Agricultural Colleges & Institutes	14	
Universities, Scientific Institutions, Colleges and Schools	13	
Private Individuals and Estates	11	
Forestry Commission, Nature Conservancy & Field Studies Council	8	
Water Authorities	6	
Other Government and Public Authorities	7	
Miscellaneous (including Industry)	2	

their motivation can only be that provided by a deep personal interest and a spirit of service. Their dedication often puts the professional to shame; more than one private observer has offered to move his home to a place where there is a serious gap in the Network.

All good observers take a pride in their work, and there is perhaps a special satisfaction in having recorded an extreme of some sort. Of all the elements observed, it seems to be sunshine which attracts particular devotion, and the hope of recording as much sunshine as possible has led to sunshine recorders being sited in some very inaccessible places on the roofs of buildings. At Penzance for example, access to the recorder involves scrambling through the mechanism of a large public clock, avoiding moving cogwheels, turning rods and suspended weights (interference with which would stop the clock), in order to emerge from the tower on to a roof. There is, however, another reason for the popularity of the inaccessible, namely security, because sunshine spheres are now very expensive items to replace. Some years ago, during the summer seasons, sunshine spheres were lost with monotonous regularity from the enclosure at Rhyl which was located near a large amusement park; most of these found their way into the tents of gypsy fortune tellers from whom they were eventually recovered by the Police. Three examples, all involving sunshine measurement, will serve to illustrate the lengths to which a dedicated observer will go in carrying out his self-imposed duty.

The station at Botwnnog in Gwynedd is located at the local school, and under the direction of Mr R. L. Jones, then Physics master, the enclosure was always impeccable with grass of bowling-green quality. When a sunshine recorder was to be installed, a firm support was needed and it was decided that nothing less than solid rock would be satisfactory; a massive stone about 6 feet high and weighing several tons was dragged on a flat wooden trolley by teams of boys over 3 miles from a local quarry.

The saddest event in the history of the Network occurred at Teignmouth in 1963. The sunshine recorder was sited at the end of the pier which was under repair at the time; a 60 foot length of decking had been removed, and the sole access was by means of a temporary gangway of single width plank with only a hand rope for support. Whilst trying to reach the pier end to change the card during a severe gale, Mr Rossiter the observer slipped or was blown into the sea and drowned.

At Shanklin, the sunshine recorder is located on the roof of the municipal theatre, and access is by means of a 30 foot vertical iron rung ladder to a catwalk above the stage, then via another ladder and a trap door to the roof. The observer Mr Hoare, aged 82 and a sufferer from chronic arthritis, had the misfortune one evening in 1977 to fall whilst on the catwalk and dislocated his shoulder. To descend the long vertical ladder was clearly impossible, but he managed to climb single handed up to the roof where he changed the sun card and eventually managed to attract the attention of a passer-by in the street below. On arrival, the Fire Brigade ladder was found to be too short to reach the roof, so he was finally rescued on a stretcher by Naval helicopter and taken to hospital for attention. After this episode he was persuaded to retire, but sent to the Office a characteristic note complaining that, unnecessarily, 'a youngish man had now been thrown on the scrap heap'.

Recognition of long service as a co-operating observer

The spirit of dedication to which reference has already been made has not surprisingly resulted in many observers continuing to contribute to the Network over very long periods. The record so far is believed to be 68 years of continuous observing. It is fitting that some official mark of recognition and appreciation should be made to those who give outstanding service to the cause of meteorology in this way, and in 1937 financial approval was obtained to make a strictly limited number of presentations of suitably inscribed barographs. Over the 42 years that this scheme has been in operation, 48 presentations have been made. A list of the recipients and their periods of observing is given in Table III. Not surprisingly, many of those honoured in this way have been great characters, and more than one was still observing in his nineties. It is not possible in an article of the present length to describe the activities of all of them, but notes on some are reproduced in an Appendix; it is apparent from these notes that the dedicated observers were men and women of wide interests, and it is more than a little surprising that despite all other activities, their meteorological work continued so regularly for so long.

Acknowledgements

I wish firstly to record the gratitude of the Meteorological Office for the work of all those observers who have contributed to the Network during the 94 years of its existence. Observations are the lifeblood of meteorology, and without this massive and continuing contribution from the Auxiliary and Co-operating Observers, the national climatological archive would be immeasurably poorer. Secondly I must express my grateful thanks to Mr G. M. Roberts who looked after the Network in England and Wales for many years, and to Mr N. F. Hirst who is still very much involved with the Network in Scotland; without their unrivalled knowledge of events and personalities, this article could not have been written.

TABLE III—AWARDS MADE TO CO-OPERATING OBSERVERS

Year of Award	Recipient	Station	Total period of observations	Total years
1937	Mr C. Webster	Gordon Castle	1879–1939	60
1937	Dr T. E. Saxby	Baltasound	1904–1952	48
1937	Mr J. Baxendell	Southport	1887–1938	51
1938	Mr G. Reid	Crieff	1907–1939	32
1938	Mr C. L. Brook	Meltham	1881–1939	58
1938	Mr C. Dales	Bournemouth	1877–1945	68
1939	Mr A. W. Shadick	Clacton-on-Sea	1901–1939	38
1939	Dr C. C. Vigurs	Newquay	1903–1936	33
1940	Mr J. Dover	Totland Bay	1887–1948	61
1940	Mr M. T. Foster	Cullompton	1911–1947	36
1940	Mr A. Lander	Canterbury	1900–1945	45
1951	Mr J. H. Willis	Norwich	1911–1948	37
1951	Miss N. G. Abercrombie	Ventnor	1923–1951	28
1951	Mr J. Ward	Welshpool	1920–1950	30
1951	Mr C. J. Liness	Buddon Ness	1909–1973	64
1951	Mr I. H. Gordon	Banff	1923–1958	35
1954	Mr K. Durston	Bude	1913–1956	43
1954	Mr J. R. Lloyd	Shinfield	1917–1963	46
1954	Mr J. G. Balk	Oxford (Radcliffe)	1903–1954	51
1954	Mr A. H. Hookham	Eastbourne	1919–1957	38
1954	Mr D. H. Owen	Birmingham (Sparkhill)	1905–1955	50
1955	Mr F. A. C. Cullen	Bognor Regis	1923–1954	31
1955	Mr W. C. Game	Rothamsted	1911–1962	51
1955	Mr J. S. Burgess	Reading University	1918–1960	42
1956	Miss M. M. Evans	Lletty-Evan-Hên	1927–1956	29
1956	Mr H. J. Sargent	Bexhill	1924–1972	48
1956	Miss E. W. Pilkington	Buxton	1923–1962	39
1956	Mr T. Wilson	Keswick	1926–1960	34
1956	Mr E. Hendy	Bolton	1907–1957	50
1959	Mr H. Clarke	Clacton-on-Sea	1924–1960	45
1962	Mr J. Sainsbury	Regent's Park	1932–1962	30
1969	Mr Seton Gordon	Duntulm	1933–1973	40
1969	Mr A. M. Campbell	Strathy	1938–1976	38
1969	Mr F. J. Harris	Newquay	1940–1971	31
1969	Rev. Father MacKillop	Fort Augustus	1929–1970	41
1971	Mr W. A. Field	Rhyl	1933–1971	38
1972	Mr W. L. Peck	Eastbourne	1929–1972	43
1973	Dr J. T. Baldwin	Penicuik	1943–	34+
1974	Mr J. C. W. Day	Walsall	1942–	35+
1974	Mr S. J. H. Ridgwell	Maldon	1939–1976	37
1975	Mr P. Potter	Gulval	1935–1975	40
1975	Miss L. Williams	Aber	1942–1975	33
1976	Mr W. Lawrie	Greenock	1941–1975	34
1976	Mr T. C. Smith	Raunds	1942–	35+
1977	Mr H. Hoare	Shanklin	1949–1977	28
1977	Mr L. Atkinson	Scole	1929–	48+
1977	Mr J. Porter	Moneydig	1933–	44+
1978	Sir Adrian Beecham	Shipston-on-Stour	1933–	44+

APPENDIX—NOTES ON SOME LONG-SERVING OBSERVERS

Mr Charles Webster
Gordon Castle 1879–1939

The station at Gordon Castle was set up by the Duke of Richmond and Gordon some time before the Network was established, and observations were first published in the *Monthly Weather Report* in 1909. Mr Charles Webster first acted as deputy to his father who was head gardener, and became Principal Observer in 1891. Like many family gardeners of his era, Mr Webster never officially retired and he carried on observing until his death in 1939 at the age of 81.

Dr T. Edmundston Saxby, OBE
Baltasound 1904–52

Dr Saxby opened the most northerly climatological station in the British Isles on the island of Unst in 1904 and kept the records there until his death in 1952 at the age of 84. Though born in Edinburgh, and a student there and in London, he went to Unst to follow his father as doctor to the island population in 1898. He was a dedicated physician and never took a holiday; indeed in 54 years he only left the island three times, once to attend a sick relative on the mainland and twice to visit Lerwick. In 1911, King Gustav of Sweden awarded him the Order of Vasa (a Swedish Knighthood) for his services to Scandinavian fishermen; the King also offered him the post of physician to the Swedish Court, but he refused to leave the island. In the late 1940s he was awarded the OBE for his services to the community.

On his arrival in 1898, Dr Saxby made his rounds on horseback, but he later introduced the first motorcar to Unst; however, he normally walked to the enclosure each morning, and it was calculated that during the 48 years he covered well over 4000 miles on foot whilst making his observations. During his early years as observer, he built a run-of-the-wind anemometer using a cyclometer, but this was completely wrecked in a severe south-easterly gale; on another occasion he recorded a wind of force 12, and had to cling to posts to prevent himself from being blown over whilst making his observations. His practice included attending to many patients from visiting fishing boats and he often found great difficulty in finding the time to continue observing; he also built clocks as a hobby, but like so many really busy men he somehow fitted in everything and his observational record never faltered. He was a much-loved and well-respected figure on the island, and on the day of his funeral all work on Unst ceased as a mark of respect.

Mr Joseph Baxendell
Southport 1887–1938

The observatory at Southport was endowed in 1871 by a retired cotton spinner, Mr John Fernley, J.P., and the first Superintendent was Mr J. Baxendell Senior, who prior to that time had held a post as 'Time-determining Astronomer and Waterworks Meteorologist', and was later elected FRS. On the death of his father in 1887, Mr J. Baxendell Junior was appointed as Superintendent and Borough Meteorologist of Southport at the very early age of 18; he held this post for nearly 50 years until his retirement in 1936, was actively connected with the station for a further two years and died in 1940, aged 70.

Throughout his life, Mr Baxendell had to contend with persistent ill health; for periods of weeks and even months he was confined to his room, yet he not only gave a thorough training to his assistants but exercised a detailed and conscientious scrutiny of their work so that the observing routine never suffered. He was particularly interested in periodicities, and also carried out statistical work on land- and sea-breezes and the association of rainfall with wind direction, contributing papers not only to the annual reports of his observatory but to the *Quarterly Journal of the Royal Meteorological Society*. It is, however, as an instrument designer that he is best remembered, his major achievements being the Baxendell Anemoscope and the Fernley recording rain-gauge. The former, which records wind directions in great detail on a separate chart, was used in the classic investigation of wind structure carried out at Cardington in the early 1930s, the results being published as a *Geophysical Memoir;* he also designed a combined head to actuate both a Dines velocity recorder and a direction recorder through a single mast.

Mr Charles Dales
Bournemouth 1877–1945

Mr Dales first became interested in the weather in the 1860s when he was a boy of 14, and started making regular observations in 1877; when Bournemouth decided in 1901 to contribute to the Network, he was appointed as Borough Meteorologist, a post he held until his retirement in 1938 at the age of 87. The enclosure was located in his front garden and the sunshine recorder on the roof of his house, to which he climbed daily until his retirement; but even after this, having handed over to his son-in-law as official observer, he continued to take an active interest until his death in 1945 at the age of 93. He attributed

his robust health in old age to the facts that he went out in all weathers, often on his bicycle, and was a total abstainer and non-smoker all his life. Like most people appointed as Borough Meteorologist he received plenty of personal and written enquiries from the local community, and his very long period of observing enabled him to take a broad view; thus he considered the occasional extreme events as no more than fluctuations to be expected, and firmly believed that there was no real evidence of climatic change since the mid-19th century.

Dr C. C. Vigurs
Newquay 1903–36
Dr Vigurs was responsible for the climatological station at Newquay from 1903 until his death in 1940 at the age of 72, but he ceased making observations in 1936. In his early days he was a motoring pioneer, owning the first car in Newquay—a de Dion. He was a man of very wide interests, being the author of several books on botany for which he acquired a national reputation, an expert genealogist, and an acknowledged authority on heraldry, folklore and legends. Despite all this and his medical practice, he also found time to contribute frequently to the *Meteorological Magazine*. He was a very unconventional and pithy writer and some of his letters to Headquarters, still preserved on the historical files, make very refreshing reading; they must have created a minor sensation at the time.

Mr C. T. Liness
Buddon Ness 1909–73
Mr Liness first started observing at Tayport in 1909 whilst he was an assistant light-keeper; he became official observer in 1913 and remained there (apart from war service) until 1927. He then moved to Buddon Ness, and although he officially retired in 1950 he was then employed for some years as a caretaker and continued observing until 1973 when he was well into his 90s. He appears to have been an exceptionally fit and active man, and at the age of 93 he appealed to his former employers for a job to keep him occupied. One of his hobbies was growing carrots. He dug a trench in the sand near the lighthouse, filled the bottom with seaweed gathered from the beach and planted his seed in open-ended tubes; the result was carrots about 18 inches long, smelling of iodine.

Mr D. H. Owen
Birmingham (Sparkhill) 1905–55
Mr Owen kept notes of local weather from 1892, but became an official observer for the British Rainfall Organization in 1905 and a full climatological observer in 1907, continuing until his death in 1955 at the age of 84. He was a keen mountaineer, and made a record ascent of Snowdon in the early 1900s. In 1905 he took part in a European contest in predicting weather trends and won his way through to the final; unfortunately this was held in Paris and he was unable to take part because of lack of funds.

Miss E. W. Pilkington
Buxton 1923–62
Miss Pilkington was appointed Borough Meteorologist of Buxton in 1923, succeeding her father who had held the post since 1899; the family connection thus lasted for over 60 years. She also took over the family pharmacy business on the death of her father, and throughout her period as Borough Meteorologist she produced a daily 24-hour forecast entitled 'Buxton Weather Prospects' written in a very bright and breezy style. After her retirement in 1962 she was appointed Curator of the Bexhill Museum.

Mr T. Wilson
Keswick 1926–60
Mr Wilson took over the climatological station at Keswick in 1926 and acted as observer until his death in 1960 at the age of 73; unfortunately the station did not long survive him. He kept a café and guest house in the town, but was also a music lover, historian and naturalist, and was a bell ringer at the local Church for over 50 years. He sang in the Church choir, founded the Keswick Male Voice Choir and was producer for the Keswick Operatic Society. He took a great interest in local history, was well known as a lecturer on Lakeland customs, folklore and dialect, and published several books on these subjects. He was a keen birdwatcher, and his summaries of local weather always included notes on ornithological events.

Mr Seton Gordon, CBE
Duntulm 1933–73
Mr Seton Gordon, the well-known Scottish naturalist and author, set up a climatological station at Duntulm on Skye in 1933. After graduating with an honours degree from Oxford and spending the First World War in the RNVR, Mr Gordon occupied many years wandering all over Scotland studying the people, animals and birds of the Highlands and Islands and gathering material for his books; during that time he lived in crofts, camped on islands

and was once marooned for nearly a fortnight on an uninhabited, unnamed island off the west coast of Scotland. In 1933 he decided to settle on Skye; there with the aid of his first wife who died in 1959 and that of his friend Mr Nicholson (only a few years younger than Mr Gordon, but invariably referred to as 'young Angus') he maintained a series of observations lasting for 40 years. His interest in meteorology stemmed from his student days and never flagged. In addition to his monthly returns, notes on the weather were sent in frequently, not only relating to Skye but to whatever part of the country he had visited that month; there are reports of snow on Ben Nevis in July, snow beds in the Cairngorms, thunderstorms off Skye and so on. Many of these notes are written on small scraps of paper sometimes no bigger than a postage stamp. Like many of his generation he was resistant to change, and when the Meteorological Office introduced a new form for returns, he stuck to the old one; he regarded metric units as the product of foreigners and declined to use them.

Mr A. M. Campbell, BEM
Strathy 1938–76

Mr Alex Campbell was a gamekeeper with the Department of Agriculture and Fisheries for Scotland for 48 years. He first started observing at Strathy in 1938 and apart from a break for war service with the Royal Air Force he kept the record at Strathy for 38 years almost single-handed; indeed for many years he never even took a holiday. Observing at Strathy is not easy, particularly during the winter months; on one occasion Mr Campbell reported drifts over 30 feet deep within a few hundred yards of the rain-gauge. In 1959, he agreed also to read a monthly gauge at Loch Strathy, some 9 miles from his home; the only access was over a rough track and there were times when his car was stuck in the mud or in deep snow-drifts; at other times he made the journey by tractor and although he always tried to get to the gauge on the 1st of each month, he was often forced to abandon his attempts. Since his retirement, Mr Campbell has been employed as a part time gamekeeper, sometimes working up to 14 hours a day during the shooting season; he is still a fit man at the age of 72, and was awarded the BEM in 1977.

Revd Father F. A. MacKillop
Fort Augustus 1929–70

Father MacKillop's interest in meteorology started in his student days whilst he was taking his M.A. in Geography. As a teaching order, the Benedictine Monks run a boys' school at the Abbey, and it was the practice in the 1920s to appoint the newest arrival on the staff as the meteorological observer. Father MacKillop was thus detailed in 1929, originally as a deputy observer; but from 1937 he became fully responsible and the unsatisfactory system of annual changes of observer ceased. Despite becoming Procurator of the Abbey and acting as village priest, Father MacKillop retained a keen interest in his meteorological work until his retirement in 1970.

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A SEPTEMBER MONSOON DEPRESSION AT MASIRAH, OMAN

By K. GRANT
(Meteorological Office, Bracknell)

SUMMARY

Details are given of the later stages of an Indian monsoon depression which travelled unusually far westwards into Arabia in September 1976.

INTRODUCTION

During the last week of August 1976 a vigorous monsoon depression crossed central India from east to west. Most of these depressions slow down and dissipate over northern India, but a few continue into the northern Arabian Sea, sometimes evolving into a mid-tropospheric depression before dying out as a surface circulation (Ramage, 1971; Rao, 1976). This one, however, maintained both a surface and mid-tropospheric circulation for over a week at the beginning of September 1976. Between the 5th and the 7th it was classified by Indian analysts as a cyclonic storm (mean winds 34–63 kn). Disturbances of this nature

are known to affect Oman very occasionally in July and August (Pedgley, 1969 and 1970), but are extremely rare in September, which is the driest month of the year at Masirah. The only measurable September rainfall at this station in the period 1943–75 was 0·01 inch (0·3 mm) in 1955. However, on 8 September 1976 the centre of the decaying monsoon depression passed almost directly over Masirah, and 4·2 mm of rain fell. The following account attempts to trace and comment on the observable features of this depression.

Data used

NOAA 4 and NOAA 5 unrectified satellite pictures received by Automatic Picture Tansmission (APT) were available, taken in both visible light and infra-red in the morning (about 05 GMT) and infra-red in the evening (about 16 GMT). Masirah surface charts, with all data to the east derived from the New Delhi radio-teletype broadcast, which could only be received for about two-thirds of the 24 hours, were also used; the amount of data from Pakistan was negligible, and very few ship reports were received. Only when the storm was near the coast of India were the surface charts of any use in placing it. For Masirah itself, hourly surface reports, 12 hourly upper winds by radar and 12 GMT radiosonde ascents were available. The anemogram and barogram were also used. Intermittent surface analyses from New Delhi and satellite tropical disturbance summaries from Washington helped to track the disturbance; the analyses were later checked using the ***Indian Daily Weather Report***.

Track of depression

It was difficult though not impossible to track the monsoon depression using satellite pictures because the major cloudiness was associated with a low or trough at 700–500 mb which was to a considerable extent divorced from the near-surface circulation. In this respect, the monsoon depression is akin to the extratropical depression rather than to the tropical cyclone. In the northern Arabian Sea in summer, circulation is most vigorous at 600 to 500 mb (Miller and Keshavamurthy, 1968). It was therefore decided to track separately the surface centre and the centre of the densest cloud mass on the satellite pictures which would most likely correspond to a maximum of medium-level vorticity.

Figure 1 shows the results of such tracking, using all available data. (The tracks have been smoothed subjectively, account being taken of the variation in reliability of the fixes.) The surface cyclonic storm centre moved out from India on 31 August. After 1 September it curved to the left, slowed down and weakened to become a depression. On the 5th it developed into a cyclonic storm again, increased in speed and moved north then north-west, skirting the coasts first of India and then of Pakistan. On the 7th it was apparently moving quite quickly (12 kn) south-westwards towards Masirah.

From the 1st to the 6th the centre of the medium-to-high cloud mass as shown on satellite pictures also appeared to move in a counter-clockwise loop, but at a considerable distance ($\approx$500 km) to the south-west of the surface centre. These relative positions of mid-tropospheric low and monsoon depression have also been noted by Miller and Keshavamurthy (1968). On the 7th the surface and upper circulations appeared to merge as the storm moved quickly south-westwards. There is some doubt here whether the upper cloud mass was associated

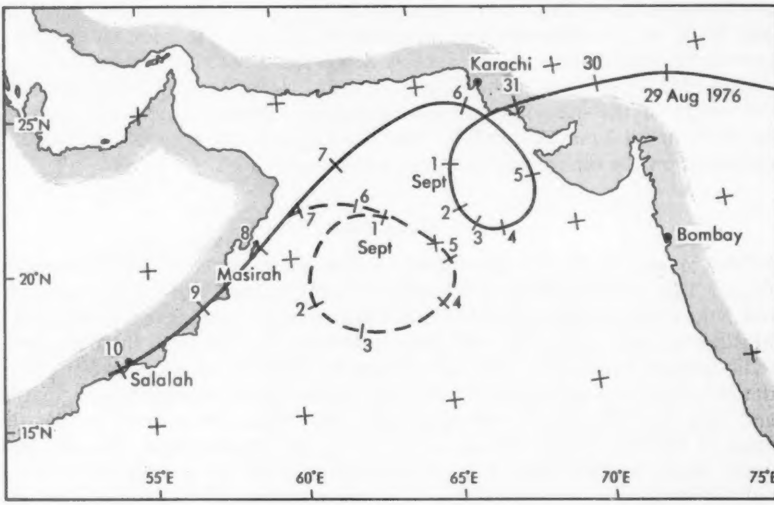

FIGURE 1—TRACKS OF MONSOON DEPRESSION (FULL LINE) AND CLOUDINESS CENTRE (DASHED LINE)

with the original positive vorticity centre, or whether a new vorticity centre was brought from the north-east by the storm. From the 7th onwards no surface centre could be seen on satellite pictures, but the upper cloud showed a more definite elliptical shape, suggesting a better-defined circulation beneath.

PASSAGE ACROSS MASIRAH

The monsoon depression crossed Masirah at about 06 GMT on the 8th, travelling south-westwards at about 7 kn ($3\frac{1}{2}$ m/s). It was difficult to decide from surface wind changes on which side it passed, but the main centre must have been within tens of kilometres. The barogram showed a drop of pressure of about 4 mb below previous and subsequent values, the minimum sea-level pressure being 1001 mb (the average 06 GMT value for the time of year is 1007 mb). A fairly steep fall occurred around 05 GMT and an equally steep rise at around 0630. Assuming that the 'eye' of the storm went directly overhead (which is not certain), this gives an eye diameter of about 20 km; no eye was visible on satellite pictures.

Surface winds were variable both before and after passage. During the hours 00–06 GMT on the 8th there were three surges of SW–SSW winds (the normal monsoon direction at Masirah); mean speeds rose to 22 kn at 0040, 20 kn at 0230, then 25–28 kn between 0445 and 0605, with the maximum gust 210° 43 kn at 0520 GMT. Between 0605 and 0630 the wind speed dropped steadily to zero, with a general backing to 060° (though oscillations of gradually diminishing amplitude with a period of 15 minutes in this lighter easterly flow caused a complete 360° veer of wind within a few minutes at 0625). Between 0830 and 1130 GMT light winds veered slowly from ENE to WSW; there was then a

further surge of SW winds, mean 21 kn, from 1245 to 1330, then very light north-easterlies. It is not known whether these surges are related to mesoscale features of the depression. They probably correspond to variations in the depth of the SW monsoon flow, which extended up to 100–200 m on this particular day.

There was light rain from about 00 to 10 GMT, though very light and intermittent after passage of the centre. The rain was moderate from 0310 to 0402 and from 0420 to about 0530, these periods coinciding with the slow increase of speed in the last surge of surface wind before the centre crossed. There was a complete cover of altostratus at an estimated height of 3000 m, with little cloud below. An interesting feature was a line of very low stratus of lenticular form at about 100 m which crossed the station from 030° at 0625 GMT, the time of the wind change.

Temperatures in the centre were 25 °C, dew-point 22 °C. In the following easterlies dry-bulb values fell to 23·4 °C. The day maximum temperature was 25·5 °C, below the previous low record for September of 26·8 °C. Table I shows the upper winds at Masirah at 00 and 12 GMT on the 8th, and upper temperatures and dew-points at 12 GMT on the 8th. There was an inversion of 4 K between 987 and 899 mb. The most noticeable feature is the veer of mid-tropospheric winds from N to NE.

TABLE I—UPPER WINDS AND TEMPERATURES AT MASIRAH ON 8 SEPTEMBER 1976

Time	Winds (°/kn) 00 GMT	12 GMT	Temperature 12 GMT °C	Dew-point 12 GMT °C
Pressure or height				
100 mb	075/39	075/33	—76·5	—
150 mb	075/30	075/28	—68·7	—
200 mb	095/24	055/17	—50·3	—
250 mb	070/21	030/21	—36·5	—45·5
300 mb	045/16	020/24	—27·1	—35·1
400 mb	350/04	010/10	—14·1	—22·1
500 mb	350/21	035/21	—5·1	—10·8
4500 m	355/37	—		
600 mb	—	045/36		
3600 m	345/25	—		
700 mb	340/21	355/29	+8·2	+4·6
2100 m	016/16	—		
800 mb	—	320/23		
850 mb	030/15	325/17	+22·6	+9·6
900 m	050/09	285/04		
600 m*	070/07	098/04		
300 m	175/08	—		
200 m*	195/16	231/05		
Surface (1001 mb at 12 GMT)	210/13	280/15	+24·6	+22·8

* These values were not included in the transmitted message but have been estimated additionally.

CONCLUSIONS

The monsoon depression which crossed India at the end of August 1976 executed a counter-clockwise loop in the northern Arabian Sea, partly as a cyclonic storm, before continuing on a south-westward track along the coast of Oman between the 7th and 10th of September. At Masirah, which received only 4 mm of rain, even though directly in the path of the depression, moderate rain was

experienced only for about three hours, that is to say, for a distance of about 50 km ahead of the centre, even though the overcast was pehaps 500 km in diameter. This fact, and the lack of gale-force winds at Masirah, suggest that the cyclonic storm had lost its intensity, presumably because of the fall of sea temperature to about 25 °C near Masirah, and the entrainment of dry air near 850 mb. The steering of the storm by winds at any particular level was difficult to determine; at high levels, a trough in the easterlies passed through Masirah late on the 8th at 300 mb and on the 10th at 100 mb, winds veering from ENE to SE.

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NOTES AND NEWS

Meteorological Office Rainfall and Evaporation Calculation System (MORECS)

The first issue of this new weekly service was made available on 5 April 1978. The information is intended for distribution by post and though primarily for use in water management and agriculture it certainly finds application in other, commercial, activities, mostly in the construction industry.

On offer are standard selections of data which experience suggests meet the needs of particular groups of customers, but the service is flexible, in that individual subscribers, if they so wish, may make a personal and more appropriate choice of data from the wide range of information available.

MORECS is an improved version of the Soil Moisture Deficit Bulletin that has been made available by the Meteorological Office for some years past. The new bulletin will be issued at more frequent intervals than in the past; certain weather variables, such as sunshine and temperature, of interest in their own right, are now presented directly, since convenient summaries arise incidentally in the steps leading to evapotranspiration estimates the basic calculations for which have also been improved.

The primary data for the calculations are taken from those arriving and handled by the automated telecommunication network of the Meteorological Office. The first step is to calculate daily values of potential transpiration or evaporation (the soil moisture loss, given that the soil water available places no restriction on the rate of loss) for each of 188 40×40 km grid squares into which Great Britain is divided in the calculation procedure. Average values for each grid square are set against interpolated average values of measured rainfall

and a day-by-day running balance is obtained. When potential transpiration exceeds current rainfall, soil moisture reserves are depleted by transpiring vegetation and the accumulated depletion is known as the soil moisture deficit. The program of calculations takes account of the different water-holding capacities of different soils, the different depths of soil explored by the roots of different crops, and the differing rates of water extraction by different crops when soil moisture reserves have been partially exhausted.

When soil moisture deficits are small, rivers and streams show a rapid response to rainfall because of run-off and surface drainage; underground water-holding strata (aquifers) are also replenished by downward percolation. As well as providing information on rainfall and evaporation, the calculations attempt to partition excess rainfall into surface run-off and percolation components. The information presented is obviously basic to the management of stream-flows, reservoirs and ground water extraction, as well as to the manipulation of soil moisture by irrigation to avoid crop production losses. Since the load-bearing capacity of the soil is dependent on the water in surface layers, the information is also highly relevant to the movement of heavy machinery, agricultural or otherwise.

Memorial plaque: the Akrotiri tragedy

A plaque in memory of Mr J. A. Flawn and other meteorological staff who died as a result of the aircraft accident at RAF Akrotiri on 7 December 1977 was put up on 21 April 1978 in the entrance hall of the Meteorological Office main headquarters building in Bracknell. (See Plate II.)

OBITUARY

We record with regret the death on 1 February 1978 of Mr B. J. Moffitt, Senior Scientific Officer, who was on secondment to the Malawian Meteorological Service.

Mr Moffitt joined the Office for the first time in 1947 as a Scientific Assistant. In 1951 he became a forecaster (Assistant Experimental Officer) and during the next 15 years served in a wide variety of forecasting posts at home and overseas, including many UK outstations, London/Heathrow Airport, and Cyprus. In 1966 he was posted to the Synoptic Climatology Branch (Met O 13) and while there decided to undertake further study. He obtained special leave to read for a B.Sc in Geography at the University College of Swansea, and took his degree in 1973. He was promoted Senior Scientific Officer in 1974. In February 1976 he was seconded to Malawi to become chief of the Climatology Branch of the Meteorological Service.

It is with regret that we record the death on 22 February 1978 of Mr C. A. Robinson, Scientific Officer, of the High Atmosphere Branch (Met O 19).

Mr Robinson joined the Office as a Scientific Assistant in 1947 and served for several years at Shawbury. After a long period overseas in the Middle East, where he was promoted Senior Scientific Assistant, he was posted to Bracknell in 1961 and served in several Headquarters Branches including Telecommunications, Operational Instrumentation and Rainfall.

In his early years in the Office he played Rugby football and later on took a great interest in railways. He was much liked by all who came in contact with him.

We record with regret the death on 14 March 1978 of Mr H. Heastie, formerly a Principal Scientific Officer at the Meteorological Office College, little more than a year after his final retirement from his post as a re-employed Senior Scientific Officer. He had become known to very many meteorologists, British and foreign, through his work at the College, where his lectures were noted for clarity of exposition and emphasis on the physical realities underlying mathematical symbolism.

Harry Heastie graduated with first-class honours in mathematics at London University in 1935 and obtained an M.Sc. in hydrodynamics and algebraic geometry in 1937. After joining the Office in 1940, he served as a forecaster in the United Kingdom and Iceland, and after the war continued to work as a practical forecaster until 1954, chiefly at London/Heathrow Airport. He then joined the Upper Air Climatology branch at Harrow, where his work led to the publication of *Geophysical Memoir* No. 103 'Upper Winds over the World'. After a couple of years in charge of Lerwick Observatory he joined the College (then known as the Training School) in 1960. He retired from his established position in 1975, but was re-employed in order to prepare the second edition of 'A Course in Elementary Meteorology'.

A man of wide general knowledge of literature and the arts as well as meteorology, Harry Heastie was regarded with affection by all his colleagues. He was always ready to take time and trouble to help individual students with their difficulties, often by showing them how a problem could be looked at in several ways, at least one of which would yield the desired illumination.

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NOTICES

It is requested that all books for review and communications for the Editor be addressed to the Director-General, Meteorological Office, London Road, Bracknell, Berkshire RG12 2SZ, and marked 'For Meteorological Magazine'.

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